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The Seed Yield of Soybean Cultivars and Their Quantity Depending on Sowing Term

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Abstract: The successful production of soybean seeds is dependent on the sowing date, because every sowing outside of the optimal time contributes to losses of yield. The aim of the study was to identify the response to sowing date of the chosen soybean cultivars by the evaluation of the length of the soybean vegetation period, yield level, its parameters and seed chemical composition. A field experiment was conducted in the years 2016–2019 at the Agricultural Experimental Station in Grabów (Masovian Voivodeship, Poland) belonging to the Institute of Soil Science and Plant Cultivation—State Research Institute in Puławy. Soybean cultivars (four in 2016–2017 and six in 2018–2019) listed in the EU Common Catalogue with various earliness were included in the experiment. Three different sowing dates were used: I—early, II—medium and III—delayed. The two-factor experiment was carried out using a split-plot design on Luvisol soil with sandy loam texture classes, in four replications. Soybean seeds were inoculated with a bacterial culture Nitragina containing strains *Bradyrhizobium japonicum*. After reaching full maturity, the most important morphological traits of 10 plants and yield components: the number of pods per plant and the number of seeds per pod were provided. After harvest, the seeds yield (kg per hectare at the 14% moisture), and 1000-seed weight were determined. The study showed that in the years with favourable weather conditions during the growing season the best yields were obtained for soybean sown on the second date, while in the year with unfavourable weather conditions, the sowing date had no significant effect on the yields. Seeds of the soybean cultivars grown under conditions of limited rainfall contained about 9% more protein than those grown under more favourable agroecological conditions. The delay of sowing date by about 20 days positively influenced the accumulation of protein in seeds.

Keywords: *Glycine max* (L.) Merrill; sowing date; weather conditions; components of yield; chemical composition

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1. Introduction

Soybean is one of the most important and valuable legume crop cultivated worldwide. World production increased from approximately 160 million tonnes on 70 million ha in 1998 to 350 million tons on 131 million ha in 2019 [1]. The European Union imports an annual average of 14 million tonnes of soybeans [2]. The area of soybean cultivation in Poland in the years 2014–2020 ranged between 12,000 and 25,000 ha and has been increasing [3]. The main reason for the increase in the acreage of soybean cultivation in Poland is primarily the growing number of cultivars adapted to cultivation in the climatic conditions [4]. Production of soybean seeds equaled 14.9 thousand tonnes, with the average yield of 2.08 t ha^{-1} [2]. Soybean has become an important source of human and animal protein, with 85% of its cultivation destined for animal feed and the remaining destined for direct human consumption [5,6]. The seeds contain about 40% protein and 20% oil [7–9].

Soybean is a species of short-day with high temperature requirements, especially during the flowering stage [10], which is a critical period associated with a particular sensitivity to low temperatures, where the air temperature in the range of 17–18 °C is considered the biological minimum, while the range of 22–25 °C is considered the optimum [11]. Temperature, apart from photoperiod, is one of the most important factors affecting the development process and growth of soybean, but which can also limit its cultivation range [12].

One of the most important soybean cultivation conditions is proper term of seed sowing because it has a significant impact on the growth, development, and yields [13–15]. It is stated that in European countries, it is possible to cultivate soybean if the vegetation period is 105–140 days long. This means that the total temperature required for the growing season should range from 1500 to 1800 °C [16]. The optimal sowing term falls in the range from mid-April to mid-May [17]. In Poland, the optimal term for the seed sowing of soybean is possible wherever soil temperature amounts to 8 °C [18,19]. This means it is usually at the turn of April and May [20]. Late sowing (after 1 May) is thought to decrease the seed yield of soybean because of summer drought stress, which reduces yield and its components [21–27]. Additionally, the delayed sowing term has a negative effect on soybean growth and development [28,29]. Kumagai and Takahashi [23] found that sowing delayed by three weeks, caused a decrease in the seed yield of soybean. According to Hu and Wiatrak [29], Jaybhay et al. [28], and Borowska and Prusiński [15] the negative impact of late sowing term is connected to unfavourable soil moisture conditions.

High air temperatures and a low rainfall increase plant transpiration. The cultivation of drought-resistant soybean cultivars in combination with the no-input agrotechnical factor, which is the sowing date, allows one to reduce the negative impact of weather on the yields [30,31].

The response of soybeans to unfavourable weather conditions depends to a large extent on the development stage, and the possibilities of plant adaptation to climatic conditions through the interaction of genetic and agrotechnical factors, which are limited and require quantification [32].

Umburanas et al. [33] stated that consequences of delayed sowing can be partially minimized by increasing the seed sowing rate.

Moreover, the quality of soybean seeds changes depending on the sowing date [15,34–37]. The same authors have suggested that seed chemical composition depends only on temperature, total rainfall and its distribution during the important development stage of soybeans [38–40].

However, seed sowing too early in unheated soil has a significant influence on prolonged and uneven seed emergence [41]. Moreover, early seed sowing must be conditioned by favourable field conditions (precipitation, temperature). Pedersen and Lauer [42] showed that an earlier sowing term for soybean resulted in a higher number of pods and seeds, and consequently, a higher seed yield than a later term.

The aim of the study was to identify the response of chosen soybean cultivars to sowing date by the evaluation of the length of the soybean vegetation period, yield, its parameters and seed chemical composition.

2. Materials and Methods

2.1. Site Experiment Description

A four-year experiment was conducted in the years 2016–2019 at the Agricultural Experimental Station in Grabów (51°21′18′′ N; 21°40′09′′ E, Masovian Voivodeship, Poland) belonging to the Institute of Soil Science and Plant Cultivation—State Research Institute in Puławy. The two-factor experiment was carried out using a split-plot design on Luvisol soil with sandy loam texture classes [43] belonging to a very good rye complex, in four replications. In the experiment, the forecrop in all the years was winter wheat. The single plot area for sowing was 24.0 m^2 in size and for harvest 21.4 m^2. Row spacing was 24 cm, sowing rate was 80 germinating seeds per 1 m^2, and sowing depth was 3–4 cm. The soybean seeds were sown by an Amazone seeder. The soil pH (in 1 M KCl) was 5.5–6.5—depending on the study year (PN-ISO 10390:1997). The content of available forms of potassium was 12.6–20.2 mg K kg^{-1} soil (PN-R-04022:1996+Az1:2002), phosphorus 11.1–13.2 mg P kg^{-1}

soil (PN-R-04023:1996) and magnesium 4.5–6.2 mg Mg kg^{-1} (PN-R-04020:1994+Az1:2004). The content of mineral N in the soil layer 0–60 cm depth was 48–52 kg ha^{-1} (PB 008-wyd.VI-06.02.2017). Mineral fertilization was applied before sowing at the following rates: P_2O_5—50 kg ha^{-1} and K_2O—90 kg ha^{-1}. Immediately after sowing, a mixture of the herbicides: Corum 502.4 SL (at a rate 1.25 l ha^{-1}, active substance: 480 g L^{-1} bentazone and 22.4 g L^{-1} imazamox; BASF, Luwigshafen, Germany) and Stomp 330 EC (at a rate 3.5 L ha^{-1} (active substance: pendimetalin—330 g L^{-1}) was applied by a KFMR Krukowiak sprayer. Soybean seeds were inoculated with a bacterial culture Nitragina containing strains *Bradyrhizobium japonicum* (IUNG-PIB, PL). The harvest was carried out at the full maturity stage (R8).

2.2. Experimental Factors

Soybean cultivars with various earliness were included in the experiment: Aldana (000) early cv. (breeder PL—HR Strzelce); Merlin (000++) semi-late cv. (AT—Saatbau); Lissabon (000) late cv. (AT—Saatbau); Annushka (0000) very early cv. (UA—HS Agroyoumis); Aligator (000) very late cv. (FR—Semences); and Abelina (000++) semi-late cv. (AT—Saatbau), which were the first-order factor. The following four cultivars: Aldana (125–130 days of vegetation), Merlin (127–132 days of vegetation), Annushka (115–125 days of vegetation), and Lissabon (133–140 days of vegetation) were included in all the years of the study (2016–2019), while the cultivars: Aligator (137–139 days of vegetation) and Abelina (128–135 days of vegetation) were included in the third and the fourth years of the study (2018–2019) only. All cultivars are listed in the EU Common Catalogue [44].

The second experimental factor was the sowing date: I—early, II—medium and III—delayed. The sowing dates are shown in Table 1.

Table 1. The soybean sowing dates from 2016 to 2019.

Sowing Date	Year			
	2016	2017	2018	2019
I	18 April	25 April	18 April	18 April
II	26 April	9 May	27 April	2 May
III	5 May	19 May	7 May	10 May

2.3. Data Collection

Right before harvest, after reaching full maturity, the most important morphological traits of 10 plants and yield components: the number of pods per plant and the number of seeds per pod were provided. After harvest, the seeds yield (kg per hectare at the 14% moisture) and 1000-seed weight were determined. Technical maturity depending on the sowing term is shown in Table 2. Soybean was harvested at the full maturity stage (BBCH 89) when 95% of the pods turned a mature pod color and when the seed had a low moisture content. The seed yield was determined for each whole plot and converted into kg per hectare at the 14% moisture content. The sum of average daily temperatures (°C) and sum of rainfall (mm) for each year (2016–2019) were counted using data from a weather station situated near the experimental fields and belonging to the Institute of Soil Science and Plant Cultivation—State Research Institute (Poland).

2.4. Chemical Analysis of Soybean Seeds

Chemical analysis of the seeds in the Certified Chemical Laboratory in Puławy was performed. The content of basic nutrients (crude protein, crude fat and crude fibre) was analyzed separately for each year as a collective sample for the object, while contents of crude ash, phosphorus and potassium were analyzed as a collective for all the years of the study.

The N content (nitrogen %) in the dry weight of seeds (DWS) was measured by the flow analysis (FA) with spectrometric detection, the total protein by the Kjeldahl distillation method [45] after mineralization in sulfuric acid, while the crude fat content was measured by the Soxhlet's method [46], crude fibre (CF) by the enzymatic-weight method [47], and crude ash (CA) by conventional methods (dry mineralization) [47]. The content of phosphorus by the continuous flow analysis (CFA) and potassium by spectrometric detection were determined.

Table 2. The technical maturity of soybean cultivars depending on the sowing date.

Year		Cultivar/Sowing Date					
2017		Annushka	Aldana	Merlin		Lissabon	
	I	15 August	18 August	26 August		22 August	
	II	4 September	6 September	10 September		9 September	
	III	20 September	23 September	26 September		26 September	
2018		Annushka	Aldana	Merlin	Abelina	Lissabon	Aligator
	I	08 August	18 August	23 August	18 August	21 August	29 August
	II	16 August	24 August	29 August	24 August	26 August	9 September
	III	24 August	4 September	10 September	4 September	7 September	20 September
2019		Annushka	Aldana	Merlin	Abelina	Lissabon	Aligator
	I	22 August	28 August	8 September	8 September	8 September	20 September
	II	2 September	12 September	18 September	18 September	18 September	28 September
	III	12 September	20 September	30 September	30 September	30 September	14 October

2.5. Data Analysis Methods

The results were statistically analyzed with the use of the variance analysis using Statistica v.10.0 program software (StatSoft, Kraków, Poland). Tukey's multiple comparison test was used to compare the differences between the means for the cropping method, while confidence intervals for the means of Least Significant Difference—LSD (α = 0.05) were used.

2.6. Weather Conditions

In the years of the study, a varied sum of rainfall was recorded during the growing season of soybean. The highest total rainfall was recorded in 2017 and 2018 and exceeded 35% that in 2019 and was 30% less than the long-term average (Figure 1). In 2016 a lower air temperature was recorded in the third decade of April, compared to the long-term average, which had a significant impact on the emergence, growth and development of soybean crop, especially those sown in the second date. A small amount of rainfall was recorded in the third decade of May and the first decade of June, which had an unfavorable effect on the development of soybean crop. A small amount of rainfall in the second decade of August resulted in the accelerated plant maturation, regardless of the sowing date. In 2017 there was a strong cooling at the end of the second decade of April, and frosts occurred at night, which caused a delay in sowing soybeans on the first date (sowing was carried out on 25 of April). At the beginning of the third decade of April and the first decade of May, the high amount of rainfall was noted (exceeded the long-term average by 77%), which made it difficult to make the mechanical treatment in the field of soybean crop. In June and the first decade of July, a small amount of rainfall compared with the multi-year average was recorded, which had a negative effect on the growth and development of soybean plants. Very little rainfall was also recorded in the first decade of August (0.9 mm), which caused premature soybean maturity. In 2018, the amount of rainfall in May and July exceeded the average from multi-years by 70.9 and 41.1%, respectively, which favored the yields of soybean. In the last year of the study (2019), little rainfall was recorded in the first and second decade of April and at the beginning of the first decade of May. Moreover, in the first and second decade of June, in July and in the first decade of August, drought occurred, which limited the growth and development of soybean. In August, in the second decade, significant rainfall was recorded, which contributed to the prolongation of the vegetation period, delayed maturation of soybean plants, and the occurrence of weed infestation, especially with *Chenopodium album* L. Moreover, in all years of the study, in July and August, high air temperatures were recorded, which additionally worsened conditions for crop yields.

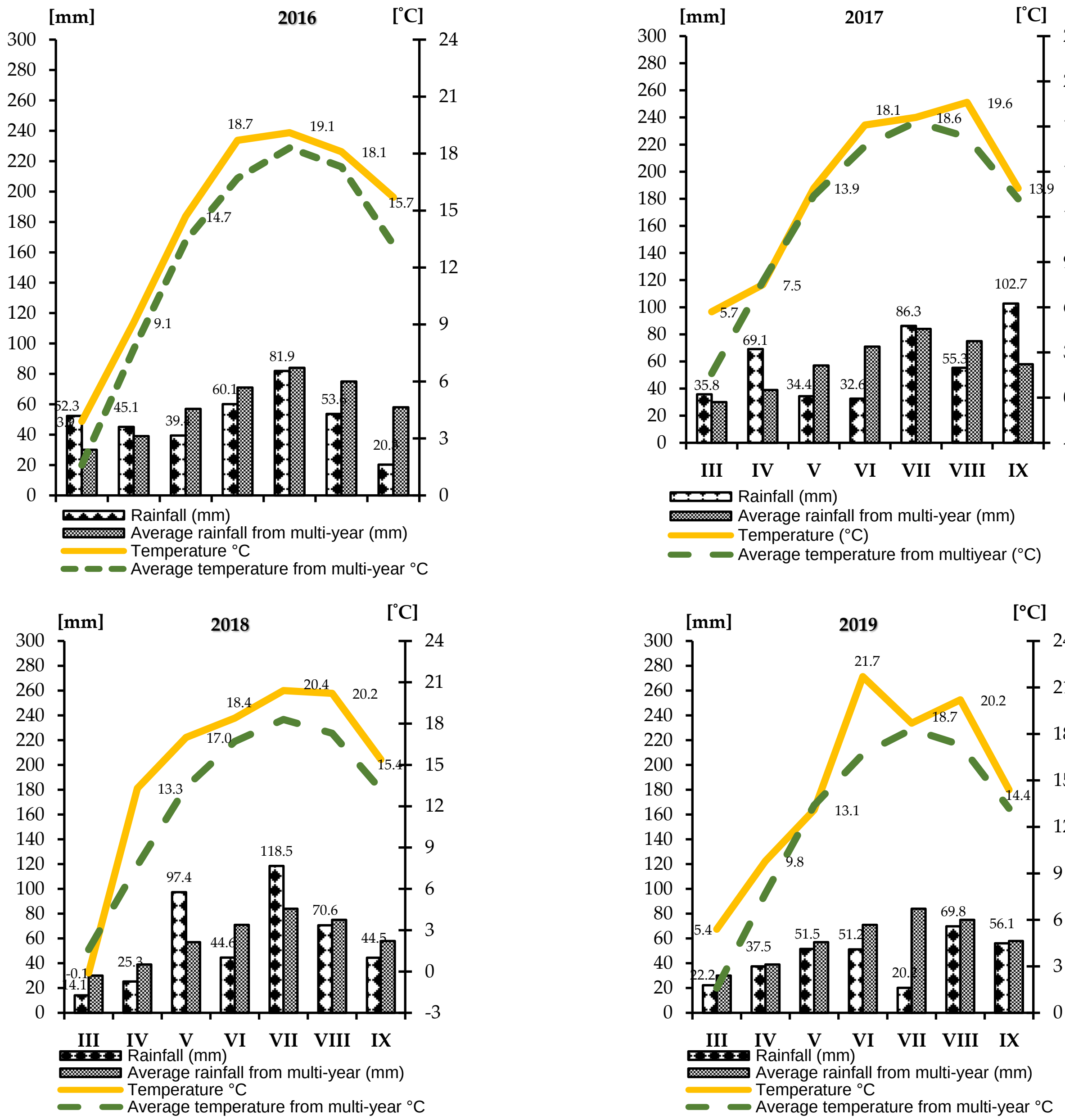

Figure 1. Monthly rainfall and temperature during the growing period from 2016 to 2019, and the long-term (1871–2000) average.

3. Results and Discussion

Regardless of the sowing date and weather conditions during the vegetation period in the region of central-eastern Poland, the cultivars reaching technical maturity for harvesting at the earliest date, were Aldana and Annushka, while the latest were Merlin and Aligator (Table 2). In the study of Włodarczyk [48], the longest vegetation period in south-western region of Poland was recorded for cultivar Aligator, while the shortest was recorded for Lissabon and Merlin. Delaying the sowing date by 20 days in relation to the earliest date resulted in the shortening of the vegetation period by 18 days. This author found that the longest growing season of soybean (142 days) was recorded, when the total rainfall in the period May-September was similar to the long-term average. A decrease in the total rainfall for this period by 23% resulted in a shortening of the growing season by 17 days. According to Serafin-Andrzejewska et al. [49], delaying the soybean sowing date under conditions of south-western Poland by 20 days resulted in the shortening of the vegetation period by 14 days. The authors stated that the growing season from emergence and the entire growing season from emergence were the shortest in the latest sowing date. Moreover, authors recorded that the delaying the soybean sowing date by 20 days in relation to the earliest date, caused a decrease in the total length of the day during vegetative development and the entire growing period by 18 and 8%, respectively, which resulted in an average increase in the length of the day during vegetative development by 0.84 h and a decrease in the length of the day during generative development by 0.27 h. Chen and Wiatrak [50] found that in Maryland (USA), the growing season length shortened with later sowing dates, and the shortening was greater for vegetative stages in relation to generative stages. The authors suggested that sowing dates in May would support a greater potential of soybean yield. Jarecki and Bobrecka-Jamro [51] indicated the shortening of growing season of soybean by 17 days due to the delayed sowing date in the conditions of the eastern region of Poland.

Włodarczyk [48] stated that the quantification of the effect of the soil moisture and thermal conditions and the studied factors (cultivars and sowing date), varied in the years, on the length of the soybean growing period depending to the greatest extent on the sowing date (46%), followed by the weather conditions (44%), and cultivar (10%). Kumar et al. [52] stated that weather conditions should be the basis for the decision of the soybean sowing date.

Soybean yields, structural yield components and content of main nutrients in seeds of the evaluated cultivars, were significantly influenced by the sowing date and the course of weather conditions (air temperature, total rainfall and its distribution) during the growing season. The impact of those factors on the yields of soybean seeds is confirmed by other authors [15,32,37,53–55]. Bosnjak [56] stated that soybean seeds' yield is positively correlated with the rainfall throughout the vegetation period, whereas Mandic et al. [55] found a high correlation between soybean seed yield and rainfall in May, July, and August. However, according to Sobko et al. [57], seed yield depends on rainfall over flowering. In our study, the highest seed and protein yields were recorded in 2018, which was associated with significantly higher total rainfall than in 2016 and 2019 and a more favourable distribution of rainfall during the growing period (Tables 3 and 4). In 2017, despite similar total rainfall during the growing season to 2018, a lower yield of about 80% was recorded. This was mainly due to low total rainfall in June, the first decade of July and August compared to the long-term average, which was not conducive to plant growth and resulted in premature plant maturation. Similar results to our own were obtained by Jarecki and Bobrecka-Jamro [18]. According to the authors, the highest soybean seed yield under the condition of south-eastern Poland in the Subcarpathian Voivodeship, was obtained in 2018 (4.81 t ha^{-1}), while the lower (by 0.28 and 0.86 t ha^{-1}, respectively) seed yields were recorded in 2017 and 2019. In turn, Faligowska et al. [58] recorded the highest average seed yield of soybean grown under the condition of west-central Poland in the Greater Poland Voivodeship in 2016, while the lowest was recorded in 2018.

Table 3. Yield of soybean seeds depending on cultivar and sowing date (t ha^{-1}).

Sowing Date	Cultivar	Year 2016	2017	2018	2019	Mean
I	Aldana	2.56 ± 0.10 *	1.79 ± 0.05	2.47 ± 0.43	0.95 ± 0.03	1.94
	Merlin	3.05 ± 0.12	1.41 ± 0.21	2.96 ± 0.09	1.23 ± 0.07	2.16
	Lissabon	3.16 ± 0.35	1.17 ± 0.03	3.00 ± 0.27	1.32 ± 0.06	2.16
	Annushka	2.65 ± 0.23	1.66 ± 0.03	2.31 ± 0.35	1.15 ± 0.03	1.94
	Aligator	-	-	2.60 ± 0.32	1.31 ± 0.04	1.96
	Abelina	-	-	2.92 ± 0.34	1.33 ± 0.03	2.12
mean		2.85	1.51	2.71	1.21	-
II	Aldana	2.26 ± 0.16	1.83 ± 0.03	2.5 5± 0.32	1.07 ± 0.06	1.93
	Merlin	2.70 ± 0.07	1.94 ± 0.17	3.21 ± 0.23	1.25 ± 0.02	2.28
	Lissabon	2.68 ± 0.09	1.63 ± 0.02	3.46 ± 0.45	1.26 ± 0.07	2.25
	Annushka	2.23 ± 0.07	1.74 ± 0.05	2.71 ± 0.02	1.17 ± 0.01	1.96
	Aligator	-	-	3.02 ± 0.08	1.34 ± 0.03	2.18
	Abelina	-	-	3.18 ± 0.10	1.35 ± 0.03	2.26
mean		2.46	1.78	3.02	1.24	
III	Aldana	2.58 ± 0.15	1.29 ± 0.06	2.61 ± 0.09	1.05 ± 0.04	1.88
	Merlin	2.90 ± 0.09	1.64 ± 0.28	3.25 ± 0.30	1.23 ± 0.01	2.26
	Lissabon	2.77 ± 0.20	1.08 ± 0.15	3.15 ± 0.26	1.24 ± 0.02	2.06
	Annushka	2.63 ± 0.11	1.48 ± 0.11	2.01 ± 0.17	1.16 ± 0.01	1.82
	Aligator	-	-	2.87 ± 0.18	1.32 ± 0.03	2.09
	Abelina	-	-	2.81 ± 0.21	1.32 ± 0.04	2.06
mean		2.72	1.37	2.78	1.22	-
Mean for cultivar		2.68	1.56	2.83	1.22	-
LSD (α = 0.05):						
Sowing date (A)		0.338 **	0.319	0.265	n.s.	
Cultivar (B)		0.367	0.405	0.644	0.155	-
B/A		n.s.	0.701	n.s.	n.s.	
A/B		n.s.	0.682	n.s.	n.s.	

* Mean ± standard error, ** Significant at $p \leq 0.05$ according to Tukey's honestly significant difference (HSD) test; n.s.—non-significant; Least Significant Difference—LSD.

Table 4. Protein yields of soybean cultivars depending on sowing date (kg ha $^{-1}$).

Sowing Term	Cultivar	Year 2016	2017	2018	2019	Mean
I	Aldana	803 ± 32.70 *	572 ± 16.79	750 ± 130.65	307 ± 10.12	608
	Merlin	1029 ± 39.69	475 ± 42.75	1024 ± 26.45	462 ± 14.76	748
	Lissabon	1066 ± 64.94	395 ± 20.94	1052 ± 77.46	499 ± 18.59	753
	Annushka	861 ± 74.16	498 ± 8.44	656 ± 98.14	372 ± 9.50	597
	Aligator	-	-	901 ± 92.27	472 ± 24.58	687
	Abelina	-	-	956 ± 91.59	479 ± 11.31	718
mean		940	485	890	432	-
II	Aldana	678 ± 48.68	560 ± 9.56	788 ± 99.63	356 ± 20.48	596
	Merlin	979 ± 25.25	632 ± 55.97	1141 ± 82.62	467 ± 7.90	805
	Lissabon	953 ± 32.09	539 ± 5.69	1277 ± 95.52	478 ± 26.87	812
	Annushka	697 ± 22.29	489 ± 14.60	817 ± 6.42	383 ± 3.62	597
	Aligator	-	-	1048 ± 62.58	499 ± 23.89	774
	Abelina	-	-	1045 ± 32.64	505 ± 9.36	775
mean		827	555	1019	448	-
III	Aldana	791 ± 46.28	404 ± 17.86	834 ± 29.63	355 ± 13.99	596
	Merlin	1086 ± 34.21	553 ± 95.45	1191 ± 91.90	465 ± 3.01	824
	Lissabon	1022 ± 73.45	385 ± 54.61	1163 ± 95.57	471 ± 7.28	760
	Annushka	836 ± 35.89	520 ± 39.40	577 ± 47.81	386 ± 3.36	580
	Aligator	-	-	1007 ± 53.41	495 ± 23.06	751
	Abelina	-	-	933 ± 68.59	498 ± 14.20	716
mean		934	465	951	445	-
Mean for cultivar		900	502	953	442	-
LSD (α = 0.05):						
Sowing date (A)		4.952 **	6.940	5.335	n.s.	
Cultivar (B)		3.859	2.153	3.69	18.657	-
B/A		6.684	3.729	6.338	32.315	
A/B		7.105	7.461	6.893	29.904	

* Mean ± standard error, ** Significant at $p \leq 0.05$ according to Tukey's honestly significant difference (HSD) test; n.s.—non-significant.

In the second and third years of the study (2017 and 2018), soybean sown in medium term (II sowing date) yielded most favourably, while in 2016, sowing on this date turned out to be the least favourable for all the evaluated cultivars. The significant amount of rainfall during this period resulted in compaction of the soil surface, which combined with the prevailing low air temperatures, delayed plant emergence and caused a slow initial growth. In addition, in the year 2019 with unfavourable weather conditions during the growing season, the sowing date had no significant effect on the yield. In the study by Serafin-Andrzejewska et al. [49], the most favourable dates for high seeds yield was the early date (I) and the medium date (II), when the greatest sum of mean daily temperatures were noted. Bateman et al. [59] found that seeds yield decreased by 26,7 kg ha^{-1} per day when soybean was sown after 20 April. Kotecki and Lewandowska [60] showed that delaying the sowing date resulted in the decrease of seeds yield by 0.17 t ha^{-1}. According to Kundu et al. [61], delayed soybean sowing date resulted in lower seeds yield because of the loss of suitable time for the growth. Mandić et al. [62] showed that delaying the soybean sowing date by 20 days (from the beginning of April to the middle of April) in Serbia resulted in a significant decrease in seed yield. Jarecki and Bobrecka-Jamro [51] recorded that the seed yield under the condition in the eastern region of Poland was not dependent on the soybean sowing date. In the study of Kumagai and Takahasi [23] and Serafin-Andrzejewska et al. [49] soybean sowing dates had a significant effect on seeds yield, but were not significantly affected by the interaction of year–sowing date–cultivar.

According to Kumagahi and Takahasi [23], the optimal soybean sowing date is one of the most important and least expensive agronomic practices that can affect seed yield. However, Kessler at al. [62] found that sowing date is more important than selection of the early cultivar. In the study of Gaspar and Conley [54] in Wisconsin, delayed the sowing date by a month combined with the unfavorable weather conditions had a negative effect on the growth, development and yield of soybean, and resulted in shortening generative development by 15 days. In the study of Kundu et al. [61], a delayed sowing date contributed to lower yield because of the loss of suitable time for the growth, similar to our research.

Many authors stated that early soybean sowing is a key agronomic element in achieving a high yield of seeds. According to Egli and Cornelius [21], earlier sowing of soybean in the southern states of the USA causes a significant increase in yield, while delaying it until the turn of May and June significantly reduces it. Those authors stated that an earlier sowing date is associated with earlier plant flowering, which allows one to avoid summer drought and reduce disease and pest pressure. However, early sowing must be conditioned by favourable conditions, such as temperature and rainfall. Staniak et al. [37] recorded that sowing term of soybean and its cultivar can have a major impact on the quantity and quality of seed yield. According to Mandić et al. [36], sowing time and genotype are important management strategies to improve yields of soybean and benefits connected with it. Those authors stated that the sowing of soybean in the first days of April could contribute to a high yield, because in this period the plants can make the most of the available rainfall. The positive impact of soybean sowing in the first decade of April on seed yield was found by Bastidas et al. [26] and Kandil et al. [63]. According to Mandić et al. [36], soybean breeding should aim to create genotypes with a deeper system of roots in order to improve water stress tolerance.

Regardless of the sowing date and prevailing weather conditions during the growing season, cultivars Aldana and Annushka yielded lower by about 11% compared to the average yield of the other four cultivars. Similar results were obtained by Jarecki and Bobrecko-Jamro [18] and Faligowska et al. [58]. However, in the study of Serafin-Andrzejewska [49] and Faligowska et al. [58], the cultivar with the higher seed yield was Lissabon. In our own study, on average for four years, the cultivars Merlin, Lissabon and Abelina yielded best in the first and second sowing dates, while cultivar Merlin yielded best in the third sowing date.

The obtained results show that sowing date and weather conditions during growing season did significantly affect the quality of seed yield, indicating a larger influence of total rainfall on protein content. In the conducted study a higher protein content (by about 9%) was characterized by soybean seeds grown under conditions of limited rainfall (2019), while in other years the content of protein was lower and at a similar level (Table 5). Mandić et al. [58] found that unfavourable weather conditions resulted in lower protein content in soybean seeds. Lima et al. [64] showed that a late sowing time resulted in a lower protein yield in the year with unfavourable weather conditions. According to Benzain and Lane [65], protein content is more dependent on environmental conditions than on the genotype. Borowska and Prusiński [15] stated that the protein yield was determined by the total rainfall, whereas Vollmann et al. [39] stated that a high content of protein depends on temperature and total rainfall over seed filling. Assefa et al. [66] showed that environmental factors differentiated the chemical composition of seeds and yield in over 70%.

Table 5. Crude protein content in soybean seeds depending on cultivar and sowing date (g kg^{-1}).

Sowing Date	Cultivar	Year				Mean
		2016	2017	2018	2019	
I	Aldana	314	319	304	324	315
	Merlin	337	337	346	377	349
	Lissabon	337	331	351	379	349
	Annushka	325	300	284	326	309
	Aligator	-	-	346	360	353
	Abelina	-	-	327	362	344
mean		328	322	326	355	-
II	Aldana	300	306	309	332	312
	Merlin	362	325	355	376	354
	Lissabon	356	331	369	379	359
	Annushka	312	281	302	329	306
	Aligator	-	-	347	374	360
	Abelina	-	-	329	374	351
mean		332	311	335	361	-
III	Aldana	306	312	320	339	319
	Merlin	375	337	367	379	364
	Lissabon	368	356	369	379	368
	Annushka	318	350	287	333	322
	Aligator	-	-	351	376	363
	Abelina	-	-	332	378	355
mean		342	339	338	364	-
Mean for cultivar		334	323	333	360	-
LSD (α = 0.05):						
Sowing date (A)		17.170 *	5.508	4.347	n.s.	
Cultivar (B)		16.306	2.692	3.709	5.972	-
B/A		28.242	4.663	6.424	n.s.	
A/B		27.648	6.520	6.340	n.s.	

* Significant at $p \leq 0.05$ according to Tukey's honestly significant difference (HSD) test; n.s.—non-significant.

The delay in sowing date had a beneficial effect on the accumulation of protein in seeds, and the increase in content in soybeans sown in delayed date (III) compared to the early date (I) was about 4.0%. Similar results were obtained by other authors [18,67–71]. Similarly, Włodarczyk [48] noted that more protein was accumulated in seeds of soybean sown in the latest term. In turn, according to Soliman et al. [35] and El-Harty et al. [70], the content of soybean seed protein decreases with delayed sowing. Similarly, in the study of Umburanas et al. [33] the delaying of seed sowing resulted in a decrease in fat content in the seed, protein and fat yield.

In our study, the chemical composition of soybean seeds was dependent on the cultivar. Irrespective of the sowing date, the seeds of cultivars Merlin, Lissabon, Aligator, and Abelina contained on average about 13% more protein than cultivars Aldana and Annushka. In the study Borowska and Prusiński [15], thecultivar Merlin had the highest protein content. Kozak et al. [40] noted that the chemical composition of soybean seeds depended to the greatest extent on weather conditions, followed by the cultivar factor. In the study of Jarecki and Bobrecka-Jamro [18], the studied cultivars (Abelina and Aligator) did not vary by protein and fat content.

In the conducted study, fat was accumulated in soybean seeds, while a lower protein content was recorded in 2017. In the first three years of the experiments (2016–2018), sowing soybeans on a delayed date (III) resulted in a significant reduction in the accumulation of fat in seeds (Table 6). On average, throughout the study period, seeds of the cultivars Lissabon and Aligator contained less fat than the other cultivars. However, in the year with less total rainfall (2019), the sowing term had no significant effect on the fat content of soybean seeds.

Table 6. Crude fat content in soybean seeds depending on cultivar and sowing date (g kg^{-1}).

Sowing Date	Cultivar	Year				Mean
		2016	2017	2018	2019	
I	Aldana	229	260	252	233	243
	Merlin	249	261	248	214	243
	Lissabon	226	249	225	204	226
	Annushka	234	264	264	218	245
	Aligator	-	-	239	225	232
	Abelina	-	-	263	226	244
mean		234	258	248	220	-
II	Aldana	244	271	262	213	247
	Merlin	237	259	243	214	238
	Lissabon	220	244	225	206	224
	Annushka	242	265	265	224	249
	Aligator	-	-	241	215	228
	Abelina	-	-	245	231	238
mean		236	260	247	217	-
III	Aldana	232	224	258	218	233
	Merlin	225	244	238	208	229
	Lissabon	216	238	220	208	220
	Annushka	235	243	242	222	235
	Aligator	-	-	236	221	228
	Abelina	-	-	241	224	232
mean		227	237	239	217	-
Mean for cultivar		232	252	245	218	-
LSD (α = 0.05):						
Sowing date (A)		4.311 *	5.556	1.010	n.s.	
cultivar (B)		2.729	3.375	3.105	3.297	-
B/A		4.726	5.846	5.378	5.710	
A/B		5.600	7.096	4.093	5.111	

* Significant at $p \leq 0.05$ according to Tukey's honestly significant difference (HSD) test; n.s.—non-significant.

Biel et al. [71] found that the cultivar of soybean had a significant effect on fat and ash content. In these authors' study, the Merlin cultivar contained more fat than Aldana.

In the year with unfavourable weather conditions (2019), soybean seeds contained two times less crude fibre than in 2016 (Table 7). In addition, in the third and fourth years of the study (2018 and 2019), soybean sown on a delayed date (III) contained about 7% and 11% less, respectively, than those sown on the first term (I). More crude fibre was concentrated in the seeds of Annushka cv., while the least was concentrated in the Alligator and Abelina cv.

Table 7. Crude fibre content in soybean seeds depending on cultivar and sowing date (g kg^{-1}).

Sowing Date	Cultivar	Year				Mean
		2016	2017	2018	2019	
I	Aldana	83.9	79.4	77.2	52.3	73.2
	Merlin	81.4	92.2	55.4	48.2	69.3
	Lissabon	98.2	81.8	60.5	44.1	71.2
	Annushka	102.1	98.3	85.1	53.6	84.8
	Aligator	-	-	72.8	51.4	62.1
	Abelina	-	-	67.4	54.6	61.0
mean		91.4	87.9	69.7	50.7	-
II	Aldana	106.1	78.3	64.2	49.6	74.6
	Merlin	110.2	80.3	55.3	46.3	73.0
	Lissabon	92.8	103.1	60.5	43.6	75.0
	Annushka	105.1	79.8	75.4	52.2	78.1
	Aligator	-	-	68.3	48.9	58.6
	Abelina	-	-	66.1	49.9	58.0
mean		103.6	85.4	65.0	48.4	-
III	Aldana	98.2	73.4	64.6	45.6	70.4
	Merlin	99.0	102.0	59.2	43.2	75.8
	Lissabon	87.4	73.7	57.3	39.4	64.4
	Annushka	100.1	100.3	77.4	49.3	81.8
	Aligator	-	-	65.6	48.4	57.0
	Abelina	-	-	64.8	46.6	55.7
mean		96.2	87.5	64.8	45.4	-
Mean for cultivar		97.0	86.9	66.5	48.1	-
LSD (α = 0.05):						
Sowing date (A)		0.235 *	0.573	0.534	0.485	
Cultivar (B)		0.290	0.887	0.747	0.756	-
B/A		0.503	1.536	1.293	1.309	
A/B		0.454	1.322	1.085	1.074	

* Significant at $p \leq 0.05$ according to Tukey's honestly significant difference (HSD) test; n.s.—non-significant.

The changeable course of weather conditions had a relatively small effect on the contents of ash, phosphorus, and potassium in the seeds of the evaluated cultivars; therefore, the results were presented as the average of four years (Table 8). The date of soybean sowing had no significant effect on the content of ash and potassium, only a slight tendency to decrease the content of phosphorus under the influence of delayed sowing date, was observed. On average, in the period of 4 years, Aldana and Annushka cv. accumulated more ash, phosphorus and potassium contents in seeds than the other evaluated cultivars.

The study of Biel et al. [72] showed that the genetic factor influenced the content of macronutrients and micronutrients in seeds. In these authors' study, the Aldana cultivar contained more potassium than Merlin. Włodarczyk [48] recorded that weather conditions varied the content of all nutrients, while cultivar factor varied only the contents of potassium, magnesium, and calcium.

The number of pods, number of seeds in a pod, seed weight, and thousand seeds weight are essential yield components [36]. In our study, changes in structural yield components of the evaluated soybean cultivars were caused by variable weather conditions during the growing season and the use of different sowing dates (Tables 9–11). The smallest seeds, number of pods, seeds, and seed weight per plant of the evaluated cultivars were produced in 2017, while the smallest number of seeds per pod were produced in 2019. In the third and fourth years of the study, the sowing date had little effect on the number of pods and seeds per soybean plant, while in the second year these traits were most favourably affected by the medium date of sowing (II) in relation to the early date (I). In addition, in 2017–2019, soybean sown on the medium date (II) had the highest weight and the number of seeds per pod changed relatively little as a result of delaying the sowing date of soybean.

Table 8. Crude ash, phosphorus, and potassium content in soybean seeds depending on cultivar and sowing date (g kg^{-1}).

Sowing Date		Cultivar	Ash	Phosphorus	Potassium
I		Aldana	62.2	8.32	2.1
		Merlin	58.4	7.99	1.9
		Lissabon	59.4	7.42	2.0
		Annushka	63.9	8.25	2.0
		Aligator	55.8	7.23	1.9
		Abelina	57.6	7.64	1.9
	mean		59.5	7.81	2.0
II		Aldana	63.8	8.45	2.2
		Merlin	57.9	7.63	1.9
		Lissabon	58.8	7.30	1.9
		Annushka	63.1	8.22	2.1
		Aligator	57.4	7.28	1.9
		Abelina	58.4	7.63	1.8
	Mean		59.9	7.75	2.0
III		Aldana	62.4	8.37	2.1
		Merlin	56.6	7.70	1.9
		Lissabon	57.9	7.34	1.9
		Annushka	61.1	7.78	2.0
		Aligator	58.0	7.31	1.9
		Abelina	59.5	7.72	1.9
	Mean		59.3	7.70	1.95
	Mean for cultivar		59.6	7.75	1.96
	LSD (α = 0.05):				
	Sowing date (A)		0.108 *	0.074	n.s.
	Cultivar (B)		0.440	0.119	n.s.
	B/A		0.762	0.205	n.s.
	A/B		0.573	0.168	n.s.

* Significant at $p \leq 0.05$ according to Tukey's honestly significant difference (HSD) test; n.s.—non-significant.

Table 9. Thousand seed weight depending on cultivar and sowing date (g).

Sowing Date		Cultivar	Year				Mean
			2016	2017	2018	2019	
I		Aldana	200.5 ± 5.60 *	158.2 ± 9.52	172.4 ± 15.35	181.8 ± 9.08	178.2
		Merlin	177.7 ± 5.26	121.4 ± 7.84	176.6 ± 5.25	168.9 ± 6.58	161.2
		Lissabon	193.7 ± 5.31	128.2 ± 5.56	181.2 ± 16.49	184.6 ± 14.10	171.9
		Annushka	135.7 ± 6.67	122.3 ± 4.95	119.9 ± 8.89	140.2 ± 6.92	129.5
		Aligator	-	-	189.5 ± 16.14	203.5 ± 10.62	196.5
		Abelina	-	-	185.6 ± 17.61	180.2 ± 5.52	182.9
	mean		176.9	132.5	170.9	176.5	-
II		Aldana	192.6 ± 2.14	160.0 ± 6.84	171.4 ± 6.74	177.9 ± 10.57	175.5
		Merlin	182.6 ± 16.12	124.1 ± 8.24	174.1 ± 9.02	169.3 ± 6.53	162.5
		Lissabon	198.6 ± 14.93	141.0 ± 5.11	186.5 ± 12.42	186.0 ± 7.98	178.0
		Annushka	134.7 ± 2.02	118.8 ± 7.12	121.9 ± 10.95	138.2 ± 3.51	128.4
		Aligator	-	-	199.8 ± 9.96	206.5 ± 10.48	203.1
		Abelina	-	-	188.2 ± 0.82	186.5 ± 5.08	187.4
	mean		177.1	135.3	173.2	177.3	-
III		Aldana	186.7 ± 7.81	130.5 ± 1.55	181.4 ± 4.15	182.7 ± 6.32	170.3
		Merlin	184.2 ± 5.13	119.6 ± 5.44	178.5 ± 11.43	167.8 ± 3.66	162.5
		Lissabon	199.6 ± 7.84	116.4 ± 12.41	187.3 ± 11.53	184.2 ± 1.38	171.9
		Annushka	134.9 ± 6.61	101.6 ± 11.42	120.2 ± 2.36	140.8 ± 3.04	124.4
		Aligator	-	-	197.1 ± 20.25	206.3 ± 4.49	201.7
		Abelina	-	-	184.0 ± 10.28	187.7 ± 0.41	185.8
	mean		176.5	120.7	174.5	178.1	-
	Mean for cultivar		176.8	128.5	173.1	177.4	-
	LSD (α = 0.05):						
	Sowing date (A)		n.s. **	3.067	1.010	0.729	
	Cultivar (B)		3.137	3.281	1.484	1.133	-
	B/A		5.434	5.683	2.571	1.963	
	A/B		7.165	5.343	2.134	1.611	

* Mean ± standard error, ** Significant at $p \leq 0.05$ according to Tukey's honestly significant difference (HSD) test; n.s.—non-significant.

Table 10. Pod number per plant depending on cultivar and sowing date (units).

Sowing Date	Cultivar	Year 2016	2017	2018	2019	Mean
I	Aldana	17.4 ± 0.33 *	12.3 ± 0.24	16.7 ± 0.16	22.3 ± 0.24	17.2
	Merlin	18.4 ± 0.33	13.3 ± 0.30	24.8 ± 0.22	28.0 ± 1.22	21.1
	Lissabon	17.9 ± 0.33	11.7 ± 0.16	20.5 ± 0.34	28.9 ± 1.45	19.8
	Annushka	19.2 ± 0.16	14.4 ± 0.24	19.4 ± 0.24	37.7± 0.41	22.7
	Aligator	-	-	23.6 ± 0.33	27.8 ± 0.57	25.7
	Abelina	-	-	24.5 ± 0.33	28.2 ± 0.33	26.4
mean		18.2	12.9	21.6	28.8	-
II	Aldana	15.7 ± 0.49	14.0 ± 0.16	16.6 ± 0.33	22.6 ± 0.41	17.2
	Merlin	16.7 ± 0.33	14.2 ± 0.23	25.2 ± 0.16	27.0 ± 0.80	20.8
	Lissabon	16.0 ± 0.33	13.1 ± 0.22	23.2 ± 0.34	27.9 ± 0.49	20.1
	Annushka	19.8 ± 0.41	15.4 ± 0.30	23.1 ± 0.31	38.9 ± 0.73	24.3
	Aligator	-	-	24.7 ± 0.24	28.4± 0.33	26.6
	Abelina	-	-	26.2 ± 0.41	27.4 ± 0.24	26.8
mean		17.0	14.2	22.3	28.8	-
III	Aldana	18.0 ± 0.82	10.3 ± 0.21	16.8 ± 0.24	23.7 ± 0.33	17.2
	Merlin	16.1 ± 0.24	12.2 ± 0.32	25.9 ± 0.32	28.0 ± 0.82	20.6
	Lissabon	17.6 ± 0.33	10.8 ± 0.50	18.9 ± 0.16	29.0 ± 1.22	19.1
	Annushka	18.6 ± 0.41	13.4 ± 0.30	20.1 ± 0.26	37.5 ± 1.26	22.4
	Aligator	-	-	25.3 ± 0.24	29.0 ± 0.80	27.1
	Abelina	-	-	23.7 ± 0.33	29.8 ± 0.32	26.8
mean		17.6	11.7	22.2	29.0	-
Mean for cultivar		17.6	12.9	22.0	28.9	-
LSD (α = 0.05):						
Sowing date (A)		0.151 **	0.111	0.451	0.488	0.028
Cultivar (B)		0.310	0.187	0.368	0.849	0.031
B/A		0.537	0.324	0.638	1.470	0.054
A/B		0.444	0.275	0.642	1.194	0.048

* Mean ± standard error, ** Significant at $p \leq 0.05$ according to Tukey's honestly significant difference (HSD) test; n.s.—non-significant.

Table 11. Seeds number per pod depending on cultivar and sowing date (units).

Sowing Term	Cultivar	Year 2016	2017	2018	2019	Mean
I	Aldana	2.05 ± 0.04 *	1.76 ± 0.05	1.87 ± 0.06	1.70 ± 0.06	1.84
	Merlin	2.13 ± 0.08	1.73 ± 0.04	2.00 ± 0.04	1.17 ± 0.06	1.76
	Lissabon	2.15 ± 0.06	2.13 ± 0.07	2.12 ± 0.05	1.37 ± 0.07	1.94
	Annushka	2.20 ± 0.05	1.83 ± 0.02	1.86 ± 0.04	1.22 ± 0.04	1.77
	Aligator	-	-	1.94 ± 0.03	1.62 ± 0.05	1.78
	Abelina	-	-	2.05 ± 0.08	1.50 ± 0.03	1.77
mean		2.13	1.86	1.97	1.43	-
II	Aldana	2.03 ± 0.05	1.79 ± 0.07	1.81± 0.12	1.68 ± 0.03	1.83
	Merlin	2.08 ± 0.09	2.15 ± 0.03	2.04 ± 0.08	1.61 ± 0.02	1.97
	Lissabon	2.18 ± 0.06	2.06 ± 0.02	1.92 ± 0.06	1.52 ± 0.04	1.92
	Annushka	2.10 ± 004	1.81 ± 0.03	1.79 ± 0.09	1.21 ± 0.03	1.72
	Aligator	-	-	1.87 ± 0.08	1.61 ± 0.03	1.74
	Abelina	-	-	1.97 ± 0.05	1.63 ± 0.02	1.80
mean		2.10	1.95	1.90	1.54	-
III	Aldana	2.08 ± 0.06	1.96 ± 0.05	1.81 ± 0.06	1.64 ± 0.03	1.87
	Merlin	2.06 ± 0.05	2.12 ± 0.06	2.09 ± 0.07	1.66 ± 0.04	1.98
	Lissabon	2.18 ± 0.05	2.18 ± 0.08	2.04 ± 0.03	1.48 ± 0.05	1.97
	Annushka	2.17 ± 0.06	2.04 ± 0.04	1.93 ± 0.05	1.24 ± 0.04	1.84
	Aligator	-	-	2.02 ± 0.06	1.54 ± 0.03	1.78
	Abelina	-	-	2.19 ± 0.08	1.51 ± 0.03	1.85
mean		2.12	2.07	2.01	1.51	-
Mean for cultivar		2.12	1.96	1.96	1.49	-
LSD (α = 0.05):						
Sowing date (A)		0.024 **	0.027	0.013	0.030	
Cultivar (B)		0.039	0.035	0.037	0.035	-
B/A		0.067	0.060	0.064	0.060	
A/B		0.057	0.053	0.049	0.053	

* Mean ± standard error, ** Significant at $p \leq 0.05$ according to Tukey's honestly significant difference (HSD) test; n.s.—non-significant.

Rehman et al. [73] found that the number of pods, number of seeds per plant, and seeds weight per plant of two soybean cultivar from late sowing date were lower than those from an early sowing date. Similar results were obtained by Mandić et al. [36]. Those authors recorded that the delaying of the sowing date of soybean resulted in a decrease in the number of pods, seeds weight per plant, and thousand seeds weight. Kumagai and Takahashi [23] stated that the number of seeds per pod was the lowest from the latest sowing date of soybean. In the study of Włodarczyk [48], the sowing of soybeans in the delayed date (III), resulted in an increase in the number of pods and seeds per plant by 43 and 40%, respectively, and a decrease in the thousand seed weight by 6%. In turn, Pedersen and Lauer [42] and Kumar et al. [74] showed that an earlier sowing date resulted in a higher number of pods and seeds than a later date. According to Kumar et al. [74], higher number of pods and seeds per pod on an early sowing date might be due to the adequate and increased availability of nutrients for the development of a higher number of pods per plant.

The cultivars Aligator and Abelina set the most pods and seeds, and produced the highest weight per plant, while the cultivar Alligator also produced the largest seeds. The cultivar Annushka had the smallest seeds and seed weight per plant, and the cultivar Aldana had the smallest number of pods and seeds per plant. Jarecki and Bobrecka-Jamro [18] found that cultivar Aligator produced the highest number of pods per plant while cultivar Abelina characterized the highest thousand seeds weight.

4. Summary

In the years with favourable weather conditions during the growing season the best yield was recorded for soybeans sown on the second sowing date, while in the year with unfavourable weather conditions, the sowing date had no significant effect on the yields of this species. The cultivars Merlin, Lissabon, Abelina and Aligator yielded about 12% better than the cultivars Aldana and Annushka during the study period. On average, for the four years of the study, the cultivars Merlin, Lissabon and Abelina showed the best yield in the first and second sowing dates (I, II), while the cultivar Merlin showed the best yield in the third sowing date (III).

Seeds of the evaluated soybean cultivars grown under conditions of limited rainfall contained about 9% more protein than those grown under more favourable agroecological conditions. The delay of sowing by about 20 days in relation to the earliest date positively influenced the accumulation of protein in seeds. Regardless of the sowing date, the seeds of the cultivars Merlin, Lissabon, Aligator and Abelina contained on average about 13% more protein than the cultivars Aldana and Annushka. Delayed sowing adversely affected the fat content of soybean seeds.

In years with favourable weather conditions, soybean seeds contained approximately 60% more fibre than in years which were unfavourable for this species. Different sowing dates had a slight effect on the accumulation of fibre, ash, phosphorus, and potassium in seeds.

The cultivars Alligator and Abelina had the highest number of pods and seeds and the highest seed weight per plant. The cultivar Annushka was characterized by the smallest number of seeds and seed weight per plant, and the cultivar Aldana by the smallest number of pods and seeds per plant.

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